Douglas E. Bernard	JPL
Steve A. Chien	JPL
Scott Davies	CMU
Gregory A. Dorais	Ames
Richard Doyle	JPL
Dan Dvorak	JPL
Charles Fry	Ames
Edward B. Gamble Jr.	JPL
Erann Gat	JPL
Bob Kanefsky	Ames
Ron Keesing	Ames
Jim Kurien	Ames
Guy K. Man	JPL
William Millar	Ames
Sunil Mohan	Ames
Paul Morris	Ames
Nicola Muscettola	Ames
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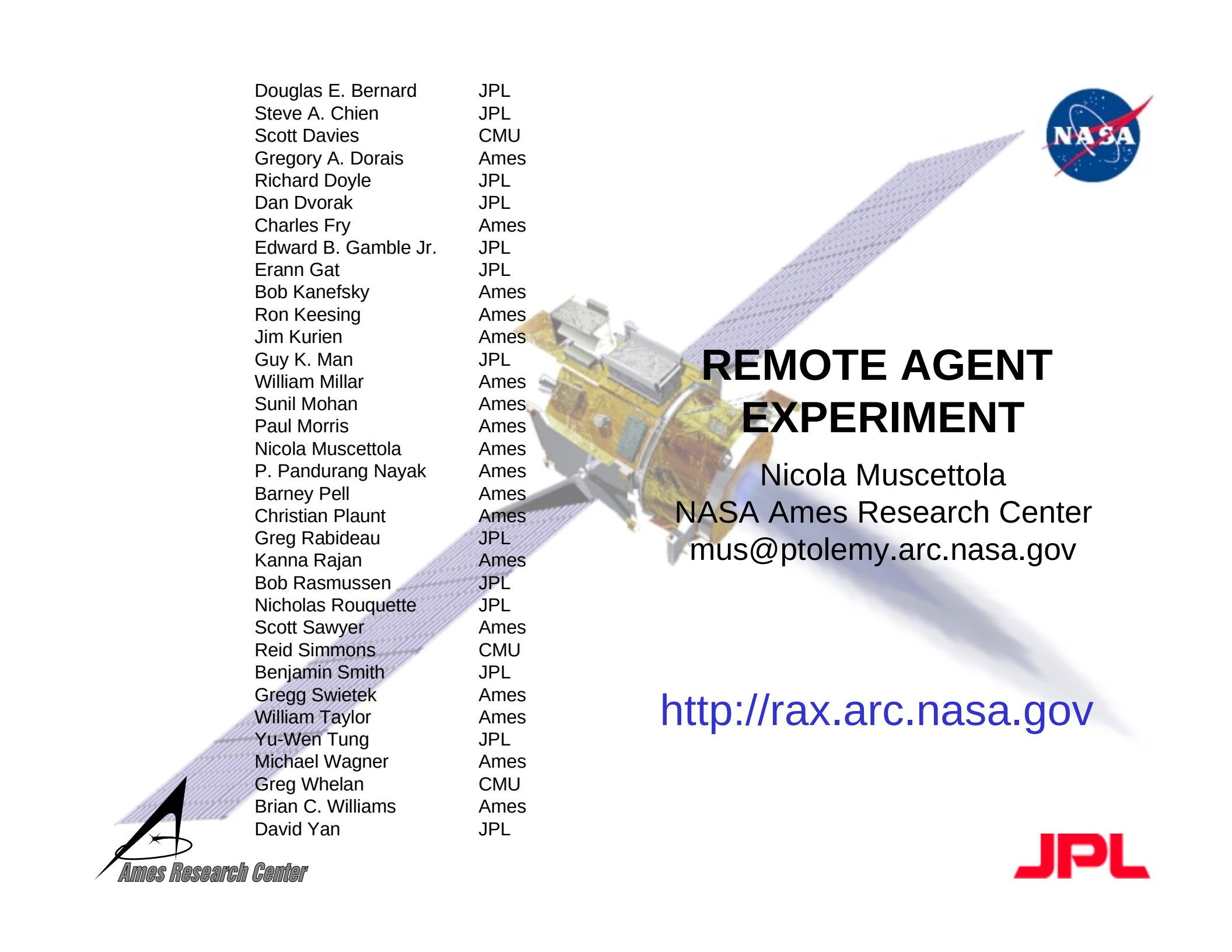
Barney Pell	Ames
Christian Plaunt	Ames
Greg Rabideau	JPL
Kanna Rajan	Ames
Bob Rasmussen	JPL
Nicholas Rouquette	JPL
Scott Sawyer	Ames
Reid Simmons	CMU
Benjamin Smith	JPL
Gregg Swietek	Ames
William Taylor	Ames
Yu-Wen Tung	JPL
Michael Wagner	Ames
Greg Whelan	CMU
Brian C. Williams	Ames
David Yan	JPL



REMOTE AGENT EXPERIMENT

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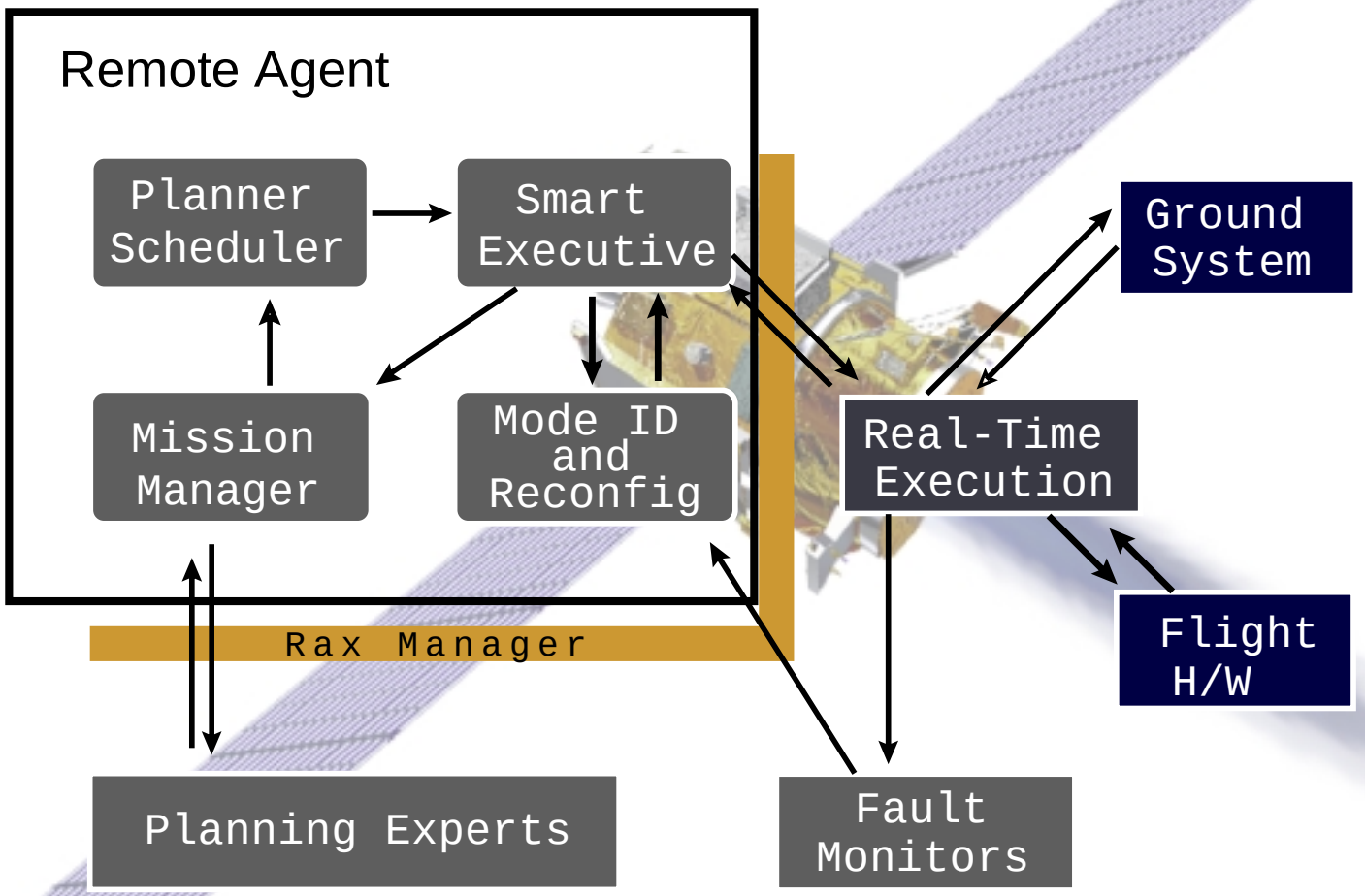
Remote Agent: an architecture for autonomy



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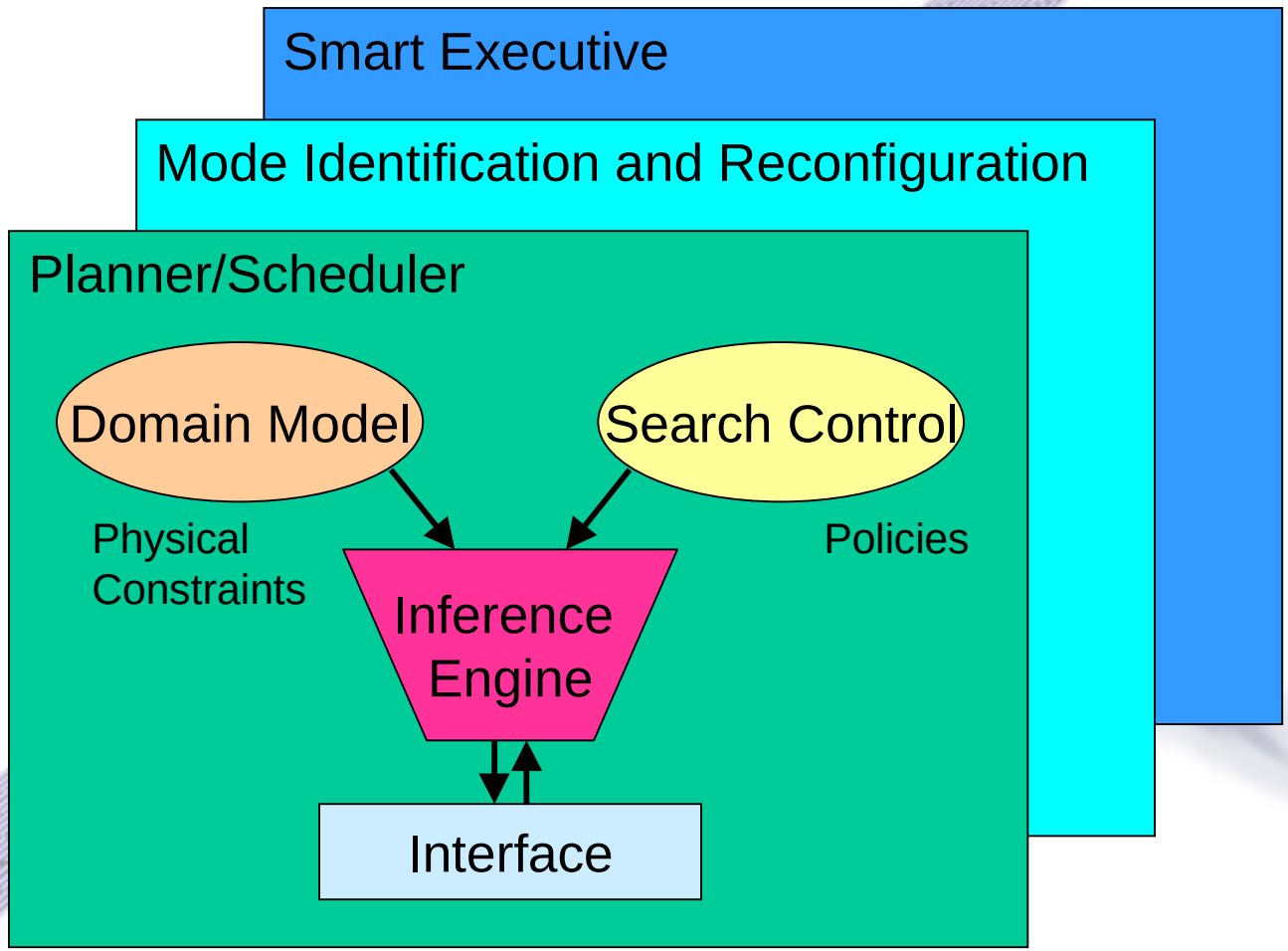
Model-based technologies



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Levels of autonomy

Level	Ground System	On-Board Planner	On-Board Exec
1	Prepare real-time commands	None	None (executed w/o Exec involvement)
2	Prepare sequence	None	Execute sequence
3	Prepare plan, upload to Exec as script	None	Execute plan; “Scripted mode”
4	Prepare plan, upload to planner as goals	Confirm and pass thru the planner	Execute plan; “Planner Mode”
5	Prepare plan including some unexpanded goals	Complete the plan	Execute plan
6	Define goals	Prepare plan	Execute plan

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Summary of RA testing

Platform	Fidelity	CPU/OS	Hardware	Availability	Speed	Number of Tests
DS1 Spacecraft	Highest	RAD6000 VxWorks	Flight	1 for DS1	1:1	1
DS1 Testbed	High	RAD6000 VxWorks	Flight spare + DS1 sims	1 for DS1	1:1	1
Hotbench	High	RAD6000 VxWorks	Flight spare + DS1 sims	1 for DS1	1:1	10
Papabed	Medium	RAD6000 VxWorks	DS1 sims only	1 for DS1	1:1	10
Radbed	Low	RAD6000 VxWorks	RAX sims only	1 for RAX	1:1	~20
Babybed	Very low	PPC VxWorks	RAX sims only	2 for RAX	7:1	>300
UNIX	Lowest	SPARC UNIX	RAX sims only	unlimited	35:1	269 (PS only)

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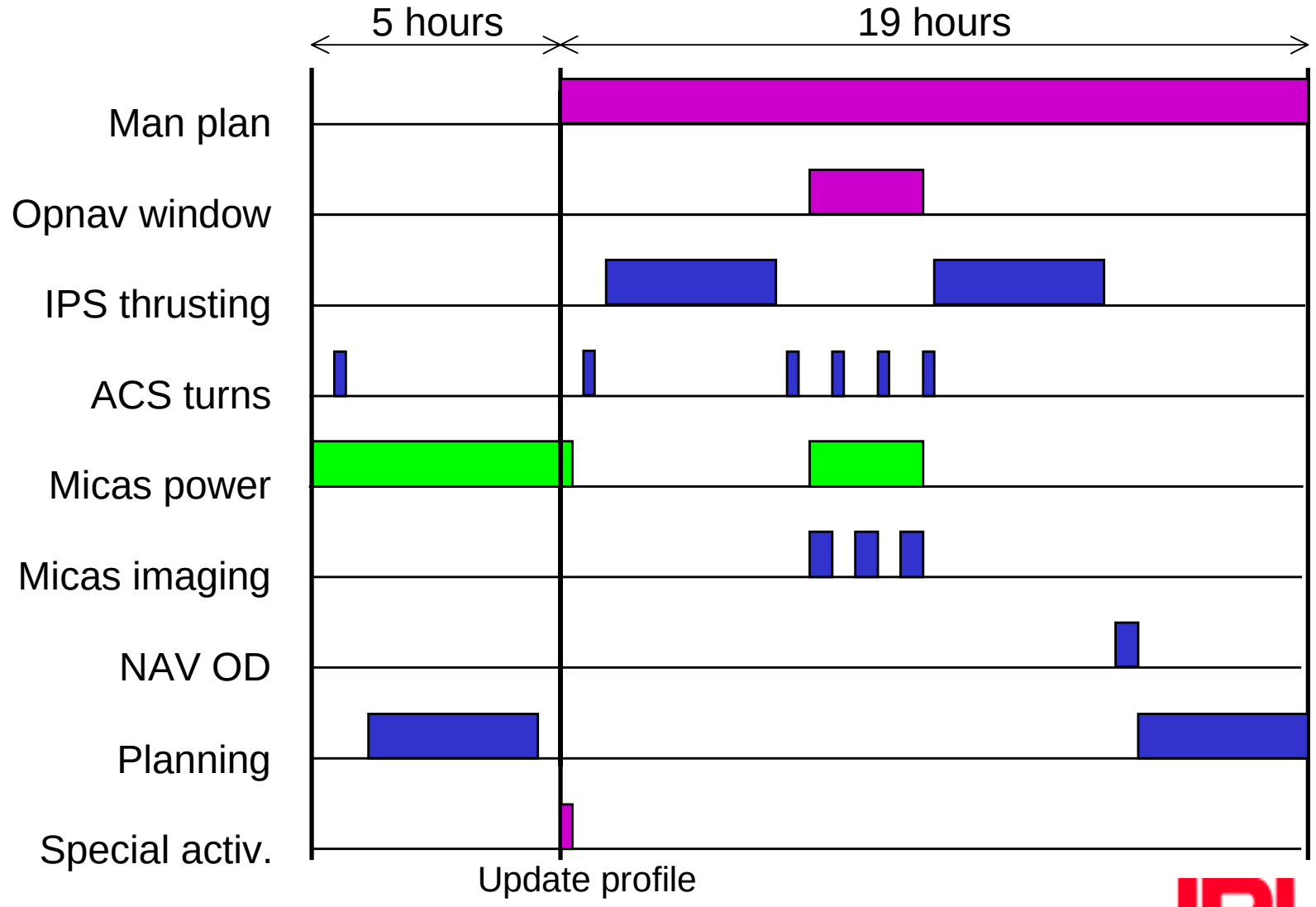
Flight experiment: first day



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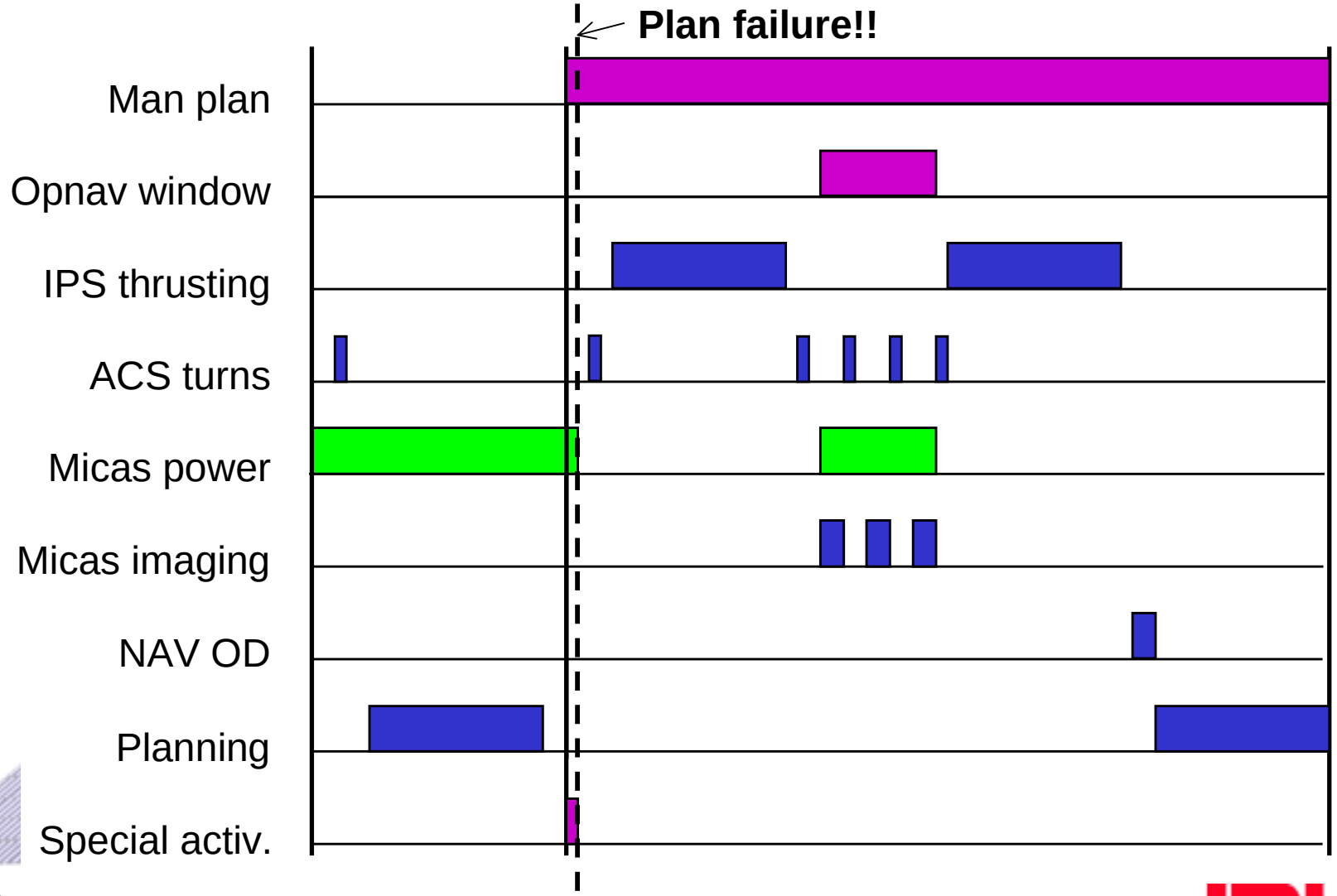
Flight experiment: simulated plan failure



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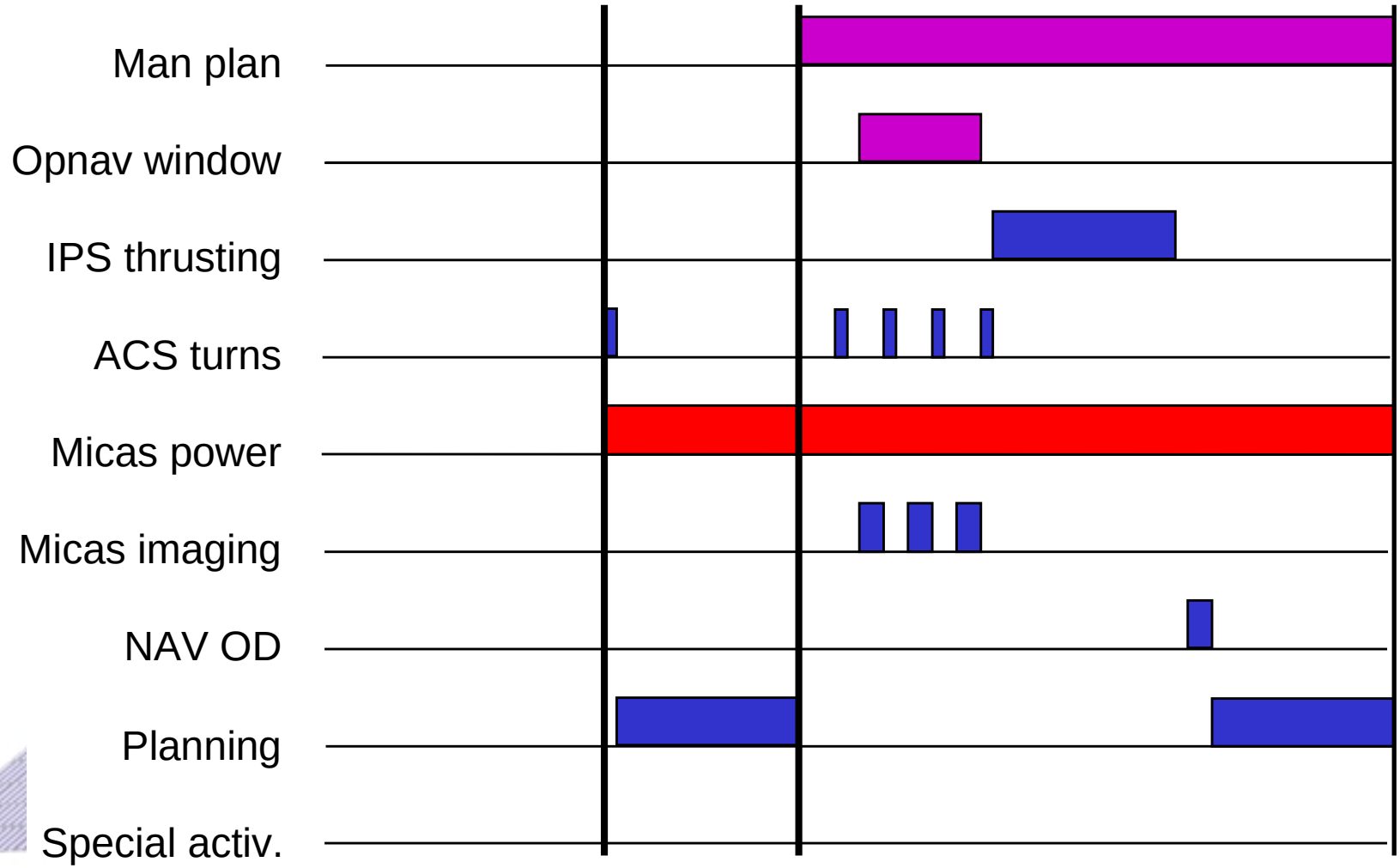
Flight experiment: replanning



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Flight experiment: second day

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Some answers to a project manager

- What does RA buy me?
  - It lowers operations costs and it enables new kind of missions.
- Does RA require more precise hardware models earlier than with normal flight software?
  - Models need to be acquired early but they are abstract and remain valid and operational throughout the project
- Is RA hard to test?
  - RA is flight software and flight software is hard to test.
  - Inference engines (reusable) may require formal validation.
  - RA's high level functions can be separately tested on low-fidelity testbeds.
- What parts of operations is RA suited for?
  - The experiment demonstrated use in cruise for a reduced spacecraft. Scale-up to a full spacecraft is likely linear.
  - Some RA components (EXEC and MIR) could already be useful on-board for critical mission phases. PS could be used during critical sequence design.
  - Full demonstration on critical mission phases will require flight test

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The Future

- Some RA concepts are being adopted by other projects such as MDS.
- A vibrant research and development program is underway at Ames to further develop RA technologies
  - MIR and PS have been re-implemented/extended in C++
  - Redesign and port of EXEC to C++ is underway
  - MIR is being deployed on X34 and X37 flight experiments
  - EXEC and MIR are being used in the JPL interferometry testbed
- Stay tuned …http://rax.arc.nasa.gov

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